KYANITE AND RELATED MATERIALS

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Kyanite, andalusite, and sillimanite are anhydrous aluminosilicate minerals with the same chemical formula (Al₂SiO₅) but different crystal structures and physical properties. When calcined at high temperatures (in the 1,400° C to 1,500° C range for kyanite and andalusite and 1,550° C to 1,625° C for sillimanite), these minerals are converted to mullite (Al₆SiO₁₃) and silica (SiO₂) (Harben, 1999). Mullite is a refractory material. During calcination, 1 metric ton (t) of aluminosilicate concentrate yields about 0.88 t of mullite. Synthetic mullite is made by heating mixtures of bauxite and kaolin or alumina and silica at about 1,550° C to 2,000° C (Roskill Information Services Ltd., 1990).

In 2000, the United States, at an estimated 90,000 t, continued to be the main producer of kyanite; reported production data are withheld to avoid revealing company proprietary information. South Africa continued as the leading producing country of andalusite, with over 185,000 t. Sillimanite has had limited production; India has supplied most of the world's output with about 12,000 metric tons per year (t/yr) in recent years.

Legislation and Government Programs

The defense national stockpile contained a total of 136 t of kyanite at yearend 2000. This material was being offered for sale on the third Thursday of every month (Defense National Stockpile Center, November 13, 2000, Kyanite, accessed March 13, 2001, at URL http://www.dnsc.dla.mil/kyanite.htm).

Production

Kyanite Mining Corp. operated two open pit mines in Buckingham County, VA, and beneficiated the ore into marketable kyanite. Some of the kyanite was calcined for conversion into mullite. Company data are proprietary, but Dickson (2000) has estimated U.S. output to be about 90,000 t/yr valued at approximately \$13.4 million (before any material was converted to mullite), using a value of \$149 per metric ton, the lowest value listed in table 1. High-temperature sintered synthetic mullite, made from calcined bauxitic kaolin and known as one of the company's Mulcoa products, was produced by C-E Minerals, Inc., near Americus, GA. Estimated U.S. production was about 40,000 t/yr (Dickson, 2000) valued at approximately \$9.7 million, using a value of about \$243 per ton. Kyanite prices, both raw and calcined, increased by about 5% early in 2000 (table 1); Mulcoa prices increased by about 4% in the first half of 1999, but there had been no further increases since then (Dickson, 2000).

Piedmont Minerals Co., Inc., in Hillsborough, NC, mined a deposit containing andalusite combined with pyrophyllite and sericite. The company sells products containing blends of the three minerals to refractories and ceramics producers. There was no known U.S. output of sillimanite.

Consumption

Refractories are the largest end use of kyanite, andalusite,

Kyanite and Related Materials in the 20th Century

Kyanite and related materials were not surveyed by the U.S. Geological Survey until 1939 and probably were not mined at the beginning of the 20th century. Test work on spark plug porcelain at the National Bureau of Standards during World War I stimulated a search for natural sources of these minerals. Andalusite was mined in California and in Nevada for spark plug insulators for the automobile industry. Andalusite mined in California from 1922 to 1936 amounted to about 18,000 metric tons. Kyanite was mined at various periods between 1925 and 1986 in California, Georgia, North Carolina, and South Carolina. In 1932, refractory uses of kyanite included boiler furnaces, brass-melting furnaces, cement kiln linings, electric furnaces, and forging furnaces. The largest long-term kyanite output had come from Virginia from around 1940 and continued into 2000. India was a major producer of kyanite, with output ranging from about 16,000 tons in 1946 to about 119,000 tons in 1970. Production then gradually decreased to the 5,000- to 10,000-ton range in the

1990s. Kyanite was mined in Kenya from about 1946 to 1955, reaching a peak production of about 23,600 tons in 1949. Reserves of easily mined massive kyanite boulders were exhausted in 1952.

In 2000, the United States was the leading producer of kyanite, with an estimated 90,000 tons. South Africa, the leading producer of andalusite, had initial production at least as early as 1939, which then generally increased over time, reaching a high of 284,000 tons in 1989. France was the other significant producer of andalusite; activity began in the early 1970s, and annual output in the late 1990s and 2000 was about 65,000 tons. High-temperature refractories had been and continued to be the largest end use of kyanite, andalusite, and sillimanite. The steel industry used an estimated 60% of refractories in general. Other applications for these heat-resistant materials are in high-temperature environments in furnaces, boilers, ladles, and kilns in the metallurgical, glass, chemical, cement, and other industries.

mullite, and synthetic mullite in the United States and worldwide. Mullite in refractories increases the fired strength, resistance to deformation under load, and thermal resistivity. Examples include insulating brick, firebrick, kiln furniture, refractory shapes, and monolithic refractories (made of a single piece or as a continuous structure), including castables (refractory concrete), gunning mixes, mortars, plastics, and ramming mixes. The interlocking grain structure of kyanite/mullite also gives much added mechanical strength to other ceramic compositions even when fired at low temperatures during manufacture. This has resulted in increased use of kyanite in sanitaryware, wall tile, precision casting molds, electrical porcelain, and other products.

Sillimanite was not known to be used in the United States in 2000.

Foreign Trade

The United States exported kyanite, mullite, and synthetic mullite to countries in Europe, Latin America, and the Pacific rim. Although the U.S. tariff code does not differentiate between kyanite, andalusite, and sillimanite, 6,230 t out of 6,440 t of total imports in 2000 were from South Africa and were presumed to be andalusite (table 2). There were no known U.S. imports of kyanite or sillimanite in 2000.

World Review

India.—Mining and mineral processing company Bajaj Associates reportedly began producing sintered mullite for use in the refractories industry. The plant, located at Bangalore, had a capacity of 10,000 t/yr. Raw kyanite feedstock, with 35% to 52% alumina, was being mined about 200 kilometers south of Bangalore. The plant was using Bajaj's own technology, including crushing, grinding, and briquetting equipment, and a rotary kiln. Output was around 800 metric tons per month (t/mo) of kyanite fines and 200 t/mo of sintered mullite for local refractory manufacturers (Industrial Minerals, 2000a).

Japan.—The Japanese refractories industry is known to be very technically advanced but was facing some difficult challenges. Production levels of refractories worldwide have fallen; refractory output tonnage in Japan is less than one half that of the mid-1970s. There has been substantial consolidation and restructuring of refractories companies in Europe and the United States in recent years. By contrast, there were still some 66 refractory manufacturers and 89 manufacturing plants in Japan in 1998. Approximately 70% of refractory demand comes from the steel industry, and many refractory producers are partly or fully owned by steel manufacturers and cement companies. There also has been a rise in imports of low-priced refractory finished products, especially from China (Pearson, 2000).

Because of a lack of indigenous mineral resources, most of Japan's refractory raw material supply was imported. With increasingly stringent requirements concerning purity and properties of refractory materials, refractory manufacturers in Japan and worldwide have turned to synthetic minerals, fused minerals in particular. Naigai Ceramics Co., Ltd., was producing 1,000 t/mo of fused mullite, mainly for hot-blast stove refractories (Pearson, 2000).

Turkey.—The Turkish refractories producer Haznedar Ateş Tuğla Sanayii AŞ was to begin production at a new refractories

plant in Istanbul. The targeted production level was 50,000 to 60,000 t/yr of high density alumina and magnesia bricks. Raw materials included calcined bauxite, andalusite, and tabular alumina (a well-sintered, high purity, coarse crystalline alpha alumina; the tabular name comes from its hexagonal tablet-shaped crystal composition) (Alcoa World Chemicals, [undated], Products, accessed April 2, 2001, via URL http://www.alumina.alcoa.com/products). Sources of imported raw materials were both local and foreign. About 70% to 75% of the refractories were for local use and the reminder for export (Industrial Minerals, 2000b).

United Kingdom.—Keith Ceramic Materials, Ltd. (KCM), a major producer of fused mullite, was acquired by the Treibacher Schleifmittel AG subsidiary of the French Imerys Group. Treibacher, the world's leading producer of fused alumina, was acquired by Imerys in the first half of 2000. KCM was producing white fused mullite and fused zirconia mullite for use in glass and steel refractories mostly for the European market (Industrial Minerals, 2000c).

Outlook

The largest user of refractories in general in the United States continued to be the iron and steel industry. Raw steel output was about 3% higher than in 1999, according to preliminary data (American Iron and Steel Institute, February 7, 2001, December steel shipments down 17.5% from previous year import surge overshadows 2000 shipment gain, accessed March 8, 2001, at URL http://www.steel.org/news/pr/2001/ pr010207 imp.htm). In the steel industry, ladle linings have continued to evolve. Ladle metallurgy has seen increasingly severe operating conditions, such as higher temperature, more chemical attack, and longer exposure time. Brick linings are still dominant in the United States, but the use of monolithics is increasing (Semler, 2000). Advances in steelmaking and other manufacturing processes have resulted in less intensive use of refractories per unit of output produced. Refractories suppliers have been developing products with superior performance and increased longevity, which require less frequent replacement and maintenance. According to Freedonia Group, Inc., opportunity for more growth for refractory products may exist in the petroleum and chemicals market. Of the major refractory forms, monolithic castables and preformed shapes are projected to be the best growth prospects (Ceramic Industry, 2000).

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TABLE 1 PRICE OF KYANITE AND RELATED MATERIALS IN 2000

(Dollars per metric ton)

	Price
Andalusite, South Africa, 57% alumina, 2,000-metric-ton bulk, f.o.b. 1/	161
Andalusite, South Africa, 58% alumina, 2,000-metric-ton bulk, f.o.b. 1/	189
Kyanite, USA (VA), 54% to 60% alumina, 35-325 mesh, 18-ton lots:	
Raw	149-182
Calcined	262-295

1/ Free on board.

Source: Industrial Minerals, no. 399, December 2000, p. 75.

TABLE 2 U.S. IMPORTS FOR CONSUMPTION OF ANDALUSITE 1/ 2/ 3/ $\,$

	Quantity	Value 4/	
Year	(metric tons)	(thousands)	
1999	6,290	\$1,330	
2000	6,440	1,320	

- 1/ Most material is from South Africa.
- 2/ Harmonized Tariff System (HTS) code: 2508.50.0000.
- 3/ Data are rounded to no more than three significant digits.
- 4/ Customs value.

Source: U.S. Census Bureau.

TABLE 3 KYANITE: ESTIMATED WORLD PRODUCTION, BY COUNTRY 1/2/

(Metric tons)

Country and commodity 3/	1996	1997	1998	1999	2000
Australia:					
Kyanite	800	800	800	1,000	1,000
Sillimanite 4/	100	100	100	100	100
Brazil, kyanite	600	600	600	600	600
China, unspecified	2,500	3,000	3,050	3,000	3,000
France, andalusite	70,000	67,000	65,000	65,000	65,000
India:					
Kyanite	6,715 5/	6,035 5/	5,169 5/	5,000	5,000
Sillimanite	7,521 5/	12,299 5/	11,936 5/	12,000	12,000
Kenya, kyanite	(6/)				
South Africa:					
Andalusite	233,728 5/	251,203 5/	236,200 5/	136,900 r/ 5/	185,055 5/
Sillimanite	5/	5/	65 5/		
Spain, andalusite	3,500	3,500	3,000	2,500	2,500
United States:					
Kyanite	W	W	90,000	90,000	90,000
Mullite, synthetic	W	W	39,000	39,000	40,000
Zimbabwe	141 5/	1,113 5/	3,780 5/	4,000	4,000

- r/ Revised. W Withheld to avoid disclosing company proprietary data. -- Zero.
- 1/ U.S. and estimated data are rounded to no more than three significant digits.
- 2/ Owing to incomplete reporting, this table has not been totaled. Table includes data available through March 20, 2001.
- 3/ In addition to the countries listed, a number of other nations produce kyanite and related materials, but output is not reported quantitatively, and no reliable basis is available for estimation of output levels.
- 4/ In addition, about 7,000 metric tons of sillimanite clay (also called kaolinized sillimanite) is produced annually containing 40% to 48% Al₂O₃.
- 5/ Reported figure.
- 6/ Less than 1/2 unit.